ERDC/EL TN-ECMI-01-02
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Ground Control Survey at Fort Benning, Georgia

by Charles D. Hahn

BACKGROUND: The Department of Defense (DoD) Strategic Environmental Research and Development Program (SERDP), Ecosystem Characterization and Monitoring Initiative (ECMI) is a long-term (more than 10 years) ecosystem characterization and monitoring program being conducted in conjunction with the host site at Fort Benning, GA. As part of this program, the U.S. Army Engineer Research and Development Center (ERDC) has developed a protocol to measure erosion/deposition dynamics in selected watershed areas on the installation (Figure 1). In order to accurately measure and remeasure the terrain surface over time, it was necessary to construct permanent ground reference points[1] in the areas to be monitored. These reference points were accurately surveyed so that the data can be directly compared to previously collected data. The most precise way to survey these reference points is to use static Global Positioning System (GPS) techniques and other precision survey techniques. However, due to the number of sites to be monitored (more than 20), a static GPS network this large would be too costly to collect and to process the GPS data.

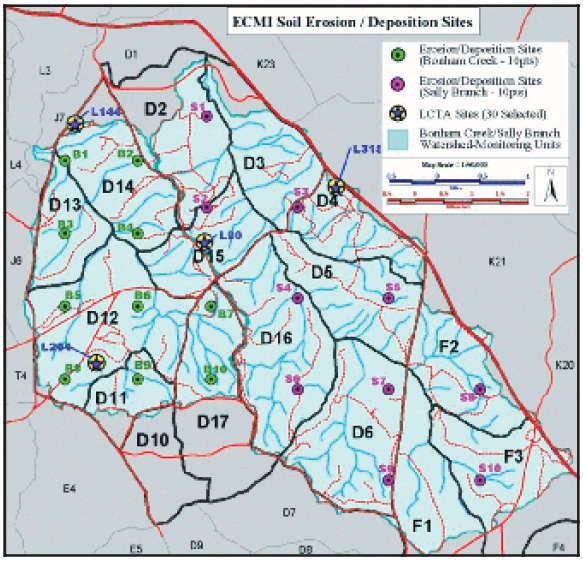

Figure 1. ECMI Soil Erosion/Deposition Sites

PURPOSE: It was decided that a combination of real-time kinematic (RTK) GPS techniques and static survey techniques would provide a much less expensive method to provide the necessary survey control at each site. A static GPS survey was used to establish a control network of high accuracy (first order standards). The reference stations (base stations) would then be used for RTK surveys to actually survey the instrument locations at the measurement sites.

LOCATION OF SURVEY CONTROL: Prior to the initiation of the survey, survey control databases at the U.S. Department of Commerce, National Oceanographic and Atmospheric Administration, and the National Geodetic Survey (NGS) were searched to locate suitable control in the area. Requirements for suitable control were first order or higher horizontal and vertical control. Several control points were identified in this search, and descriptions were printed. The locations of these control points were then plotted on a map in the Delorme Street Atlas (Figure 2). On 23 March 2001, a ground search was initiated to physically locate selected control points and flag them

1 For the purposes of this document, reference points are the points constructed as part of this survey. Control points refer to survey control points published by the National Geodetic Survey (NGS).

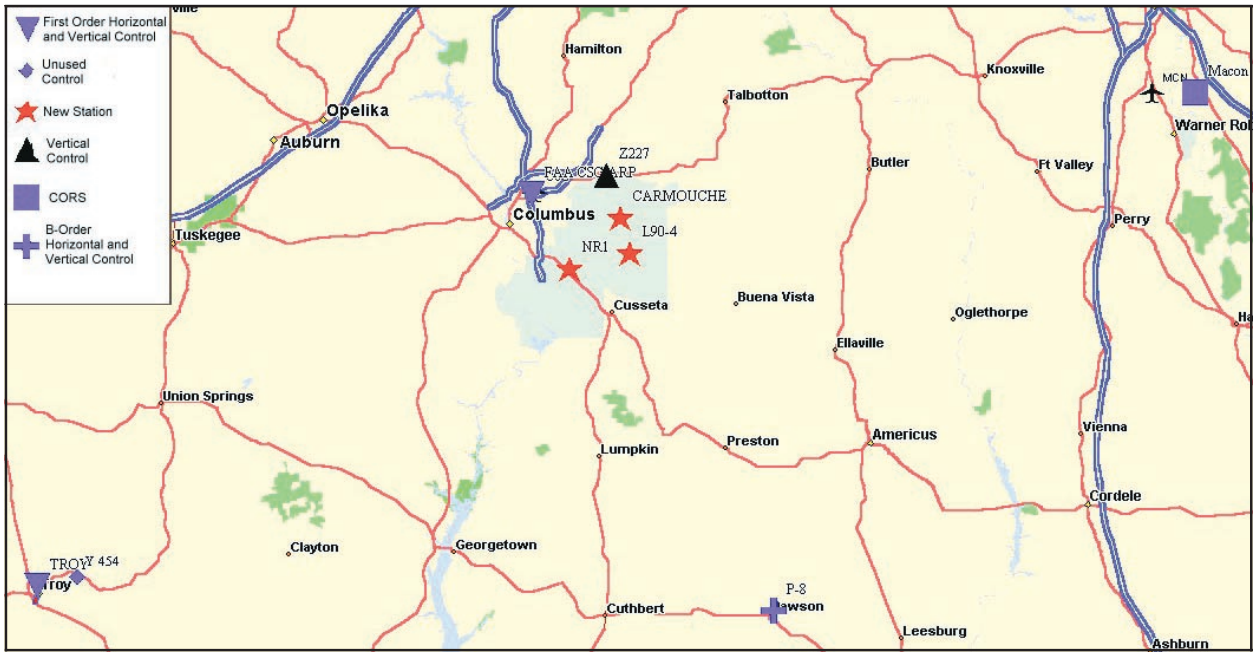

Figure 2. Static GPS Network

for later use. Control points Troy and Y 454 were located to the southwest, FAA CSG ARP to the northwest, and P-8 to the southeast. No suitable control point was located to the northeast. A second search was made of the NGS database to determine if a suitable vertical control point could be located. Z227 was located north of Fort Benning in a position suitable for use with GPS. Additionally, Continuously Operating Reference Stations (CORS) at Miller's Ferry, Alabama, and Macon, Georgia were selected to be included in the survey.

Acquisition of GPS Data: During the period 24-25 March 2001, reference points were installed at three locations on Fort Benning. These locations are at the Carmouche range (CARMOUCHE) adjacent to the ERDC weather station,[1] near the Natural Resources complex (NR1), and at the back site location for LCTA site 90 (L90-4). Each reference point consisted of a 2.5-in. (6-cm) aluminum hub affixed to a 48-in. (1.22-m) piece of galvanized steel conduit driven flush with the ground. A 6-in.- (15-cm-) diameter by 20-in. (51-cm) PVC collar was placed around the hub, and poured full of concrete. Each hub was stamped with the designation and a centering mark. GPS data were acquired on 26 and 27 March 2001. Trimble 4000 SSE and 4700 GPS receivers were used. The data collection sessions were from 0900 until 1700 EST. Data were not collected from Y 454 because this was an alternate station. On 26 March, data were collected on Troy, P-8, and FAA CSG ARP. On 27 March, data were collected at Z227, the local network (CARMOUCHE, NR1, and L144-4), and the two CORS. All GPS data were divided into 2-hr segments for initial baseline processing using the Trimble Navigation Wave® Processor.

Network Adjustment: Once the baselines (solutions between each pair of stations) were processed, network adjustment processing was begun, using the Trimble Navigation Trimnet® Network Adjustment package. Apriori errors (antenna height errors and centering errors) were set,

1 ERDC has a network of 10 meteorological stations at Fort Benning supporting the SERDP ECMI program.

and the coordinates of the Macon CORS were fixed. The network was then adjusted until it passed the chi-squared test (a statistical test of network fit). Final adjustment results met first-order accuracy standards (precision 1:100,000 or higher) with the lowest precision report of 1:160,196 (CARMOUCHE to Z227, a distance of 8,765 m). The horizontal 1-sigma error (amount of uncertainty) on this line was 5.47 cm. The average 1-sigma uncertainty for the control point CARMOUCHE was 4.11 cm, for L90-4 it was 3.57 cm, and for NR1 it was 3.73 cm. Complete covariance results are included in Appendix A. Error ellipses and the 1-sigma error histogram are included in Appendix B. Final NAD83 latitude/longitude and Universal Transverse Mercator (UTM) postions are shown below.

Point Name	Latitude	Longitude	Northing (m)	Easting (m)	Elev. (m)
CARMOUCHE	32°28'27.71346"N	84°45'35.14701"W	3595227.975	710528.565	141.503
L90-4	32°24'43.16995"N	84°44'19.51594"W	3588357.580	712853.787	146.385
NR1	32°23'04.47438"N	84°51'58.77084"W	3585066.575	700711.167	140.581

RTK Survey: After the reference network had been surveyed and the final positions computed, RTK surveys were conducted to establish control for the microtopography surveys. Three monuments were constructed as above at each site for occupation by Leica TCA 1102 robotic total stations and a fourth was constructed for use as a back site. Each of these positions was occupied with an RTK rover GPS receiver and if possible, four separate occupations were recorded for each point. These points were then averaged to compute the final position. These positions and the associated accuracies are included as Appendix C.

POINTS OF CONTACT: For additional information, contact Mr. Charles D. Hahn, U.S. Army Engineer Research and Development Center, Environmental Laboratory, Vicksburg, MS (601-634-3529, *Charles.D.Hahn@erdc.usace.army.mil*).

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The work was performed under the direction of the Ecosystem Evaluation and Engineering Division (EE) of the Environmental Laboratory (EL), U.S. Army Engineer Research and Development Center (ERDC). The EL Principal Investigator was Mr. Charles D. Hahn and Co-Investigators were Mr. Mark R. Graves and Dr. David L. Price, EL. Project Manager for the ECMI is Mr. Harold W.

West, EL, and Program Manager for the SEMP is Dr. Harold E. Balbach of the Construction Engineering Research Laboratory (CERL), ERDC, Champaign, IL.

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At the time of publication of this technical note, Acting Director of EL was Dr. Edwin A. Theriot and Chief of EE was Dr. David J. Tazik. Dr. James R. Houston was Director of ERDC, and COL John W. Morris III, EN was Commander.

Appendix A
Covariant Matrix

SUMMARY OF COVARIANCES
NETWORK = FtBenning
TIME = Thu Mar 29 09:21:19 2001

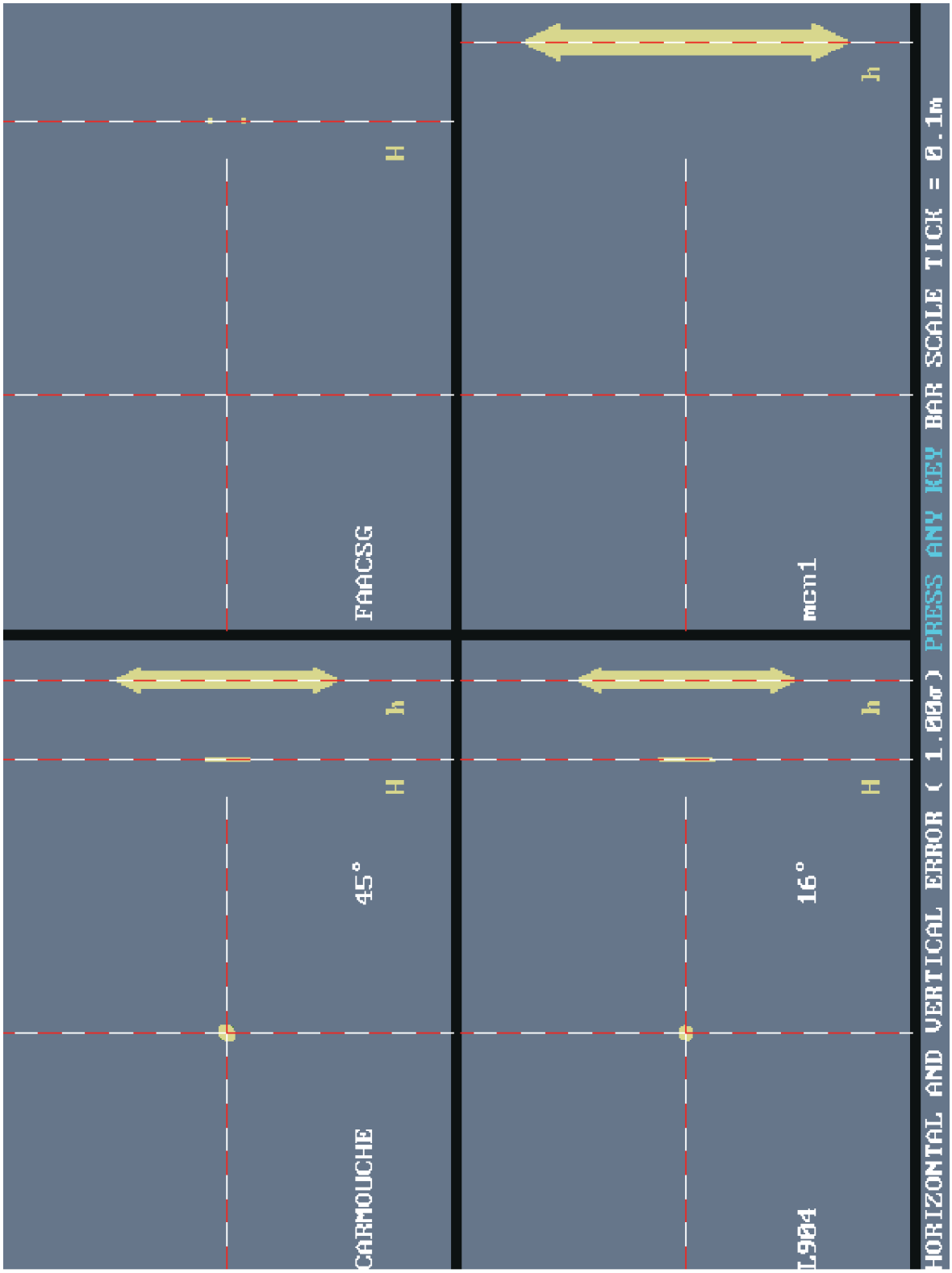
Definition of precision $(E \times S)^2 = C^2 + P^2$:
  Horizontal:
    Precision (P) expressed as: ratio
    Propagated linear error (E): U.S.
      (standard error of adjusted horizontal distance)
    Scalar (S) on propagated linear error: 1.0000
    Constant error term (C): 0.0000
  3-Dimensional:
    Precision (P) expressed as: ratio
    Propagated linear error (E): U.S.
      (standard error of adjusted slope distance)
    Scalar (S) on propagated linear error: 1.0000
    Constant error term (C): 0.0000
    Using orthometric height errors

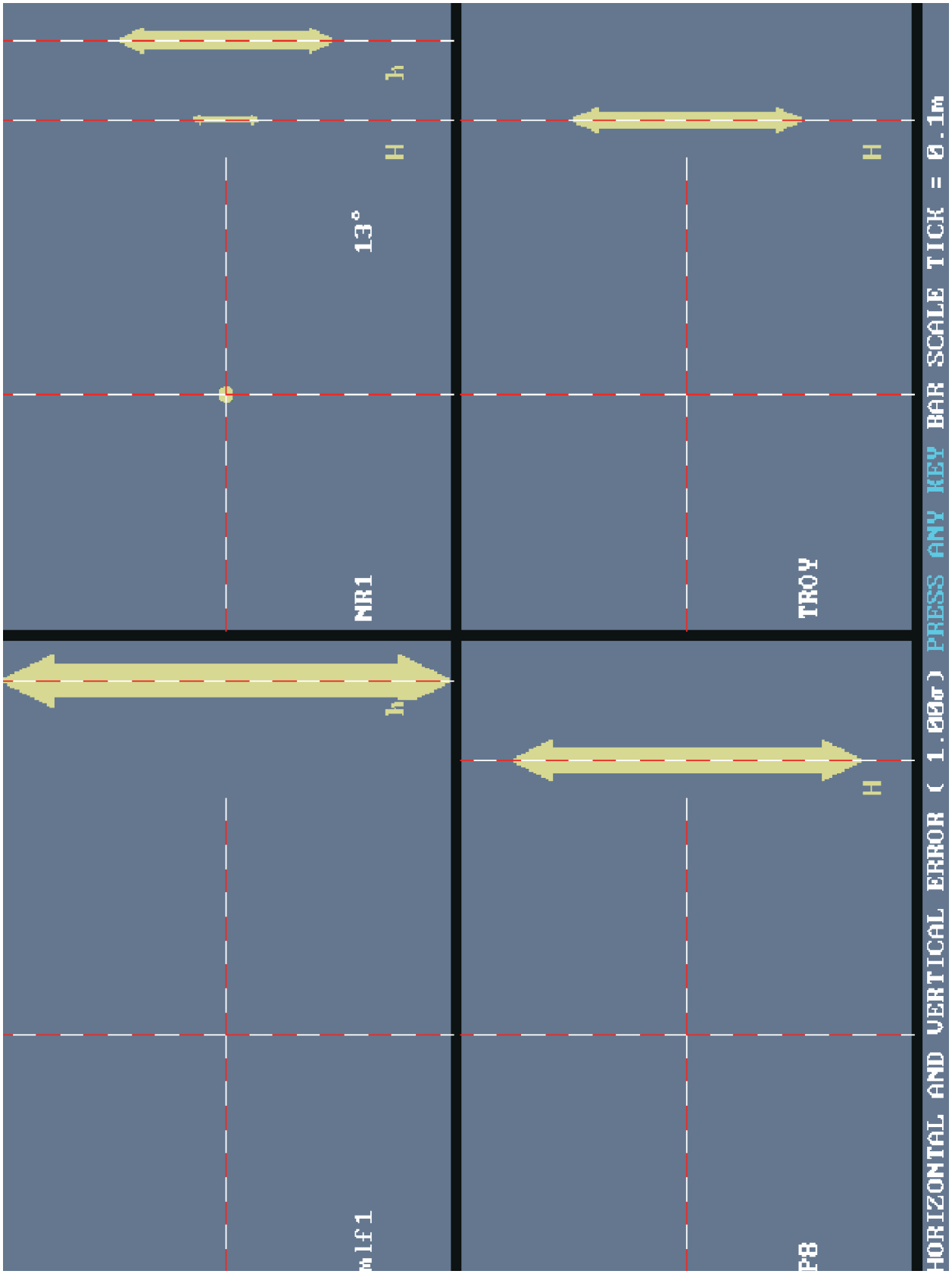
FROM/ TO	AZIMUTH/ DELTA H	1.00σ 1.00σ	DISTANCE/ DELTA h	1.00σ 1.00σ	HOR PREC/ 3-D PREC
CARMOUCHE	284°51’29"	0.46"	17839.630m	0.0363m	1: 491469
FAACSG	-24.7607m	0.2365m	-23.4257m	0.9297m	1: 491469
CARMOUCHE	164°03’15"	1.04"	7193.446m	0.0344m	1: 209140
L904	+5.9803m	0.2187m	+4.8826m	1.0809m	1: 209140
CARMOUCHE	77°23’58"	0.07"	115226.745m	0.0396m	1: 2912940
mcn1	-53.1813m	0.2156m	-52.8150m	1.3480m	1: 2912940
CARMOUCHE	260°57’26"	0.03"	251570.304m	0.0392m	1: 6423207
mlf1	-104.4333m	0.2156m	-102.9075m	2.0849m	1: 6423207
CARMOUCHE	225°12’55"	0.51"	14127.521m	0.0382m	1: 369900
NR1	+0.1689m	0.2302m	-0.9221m	1.0842m	1: 369900
CARMOUCHE	158°32’21"	0.10"	82704.926m	0.0355m	1: 2327300
P8	-22.8858m	1.3509m	-33.3707m	0.9297m	1: 2327300
CARMOUCHE	238°12’26"	0.05"	135497.609m	0.0411m	1: 3296740
TROY	+36.2980m	0.8616m	+29.9163m	0.9297m	1: 3296740

CARMOUCHE	342°01’20"	1.37"	8765.339m	0.0547m	1: 160196
Z227	-10.6170m	0.3744m	-9.1377m	0.9297m	1: 160196
FAACSG	120°46’35"	0.29"	22392.671m	0.0315m	1: 710361
L904	+30.7411m	0.2808m	+28.3084m	0.9035m	1: 710361
FAACSG	-**-	-**-	-**-	-**-	-**-
mcn1	-28.4205m	0.1806m	-29.3893m	1.3520m	-**-
FAACSG	-**-	-**-	-**-	-**-	-**-
mlf1	-79.6725m	0.1806m	-79.4818m	1.8365m	-**-
FAACSG	153°29’09"	0.44"	16220.077m	0.0328m	1: 494221
NR1	+24.9296m	0.2986m	+22.5036m	0.8869m	1: 494221
FAACSG	-**-	-**-	-**-	-**-	-**-
P8	+1.8750m	1.4730m	-**-	-**-	-**-
FAACSG	-**-	-**-	-**-	-**-	-**-
TROY	+61.0588m	0.9782m	-**-	-**-	-**-
FAACSG	75°23’23"	0.77"	15016.830m	0.0613m	1: 245089
Z227	+14.1438m	0.3382m	-**-	-**-	1: 245089
L904	73°49’55"	0.05"	115031.323m	0.0333m	1: 3453898
mcn1	-59.1616m	0.2651m	-57.6977m	1.3387m	1: 3453898
L904	262°35’17"	0.02"	252535.807m	0.0332m	1: 7599352
mlf1	-110.4136m	0.2651m	-107.7901m	2.0948m	1: 7599352
L904	255°49’12"	0.52"	12381.228m	0.0331m	1: 373552
NR1	-5.8114m	0.1328m	-5.8048m	1.0741m	1: 373552
L904	158°01’35"	0.09"	75547.939m	0.0299m	1: 2525027
P8	-28.8661m	1.2284m	-38.2534m	0.9035m	1: 2525027
L904	241°11’05"	0.05"	133712.475m	0.0331m	1: 4034022
TROY	+30.3177m	0.7403m	+25.0336m	0.9035m	1: 4034022
L904	342°56’58"	0.73"	15956.300m	0.0533m	1: 299604
Z227	-16.5973m	0.4215m	-14.0204m	0.9035m	1: 299604
mcn1	-**-	-**-	-**-	-**-	-**-
mlf1	-**-	-**-	-50.0925m	2.7960m	-**-
mcn1	254°39’33"	0.05"	127405.824m	0.0349m	1: 3647104
NR1	+53.3502m	0.2841m	+51.8929m	1.3924m	1: 3647104

mcn1	-**-	-**-	-**-	-**-	-**-
P8	+30.2955m	1.4426m	+19.4443m	1.3520m	-**-
mcn1	-**-	-**-	-**-	-**-	-**-
TROY	+89.4793m	0.9546m	+82.7313m	1.3520m	-**-
mcn1	262°20’46"	0.10"	116375.816m	0.0612m	1: 1900691
Z227	+42.5643m	0.3395m	+43.6773m	1.3520m	1: 1900691
mlf1	81°31’12"	0.03"	240245.289m	0.0349m	1: 6879552
NR1	+104.6022m	0.2841m	+101.9854m	2.0237m	1: 6879552
mlf1	-**-	-**-	-**-	-**-	-**-
P8	+81.5475m	1.4426m	+69.5368m	1.8365m	-**-
mlf1	-**-	-**-	-**-	-**-	-**-
TROY	+140.7313m	0.9546m	+132.8238m	1.8365m	-**-
mlf1	77°34’07"	0.05"	250358.643m	0.0613m	1: 4086735
Z227	+93.8163m	0.3395m	+93.7698m	1.8365m	1: 4086735
NR1	148°55’58"	0.09"	78195.027m	0.0329m	1: 2375377
P8	-23.0547m	1.2122m	-32.4486m	0.8869m	1: 2375377
NR1	239°38’40"	0.06"	121773.148m	0.0347m	1: 3505535
TROY	+36.1291m	0.7235m	+30.8384m	0.8869m	1: 3505535
NR1	21°45’37"	0.60"	19700.529m	0.0537m	1: 367187
Z227	-10.7859m	0.4329m	-8.2156m	0.8869m	1: 367187
P8	-**-	-**-	-**-	-**-	-**-
TROY	+59.1838m	0.5556m	-**-	-**-	-**-
P8	339°02’34"	0.14"	91455.625m	0.0561m	1: 1628792
Z227	+12.2688m	1.5201m	-**-	-**-	1: 1628792
TROY	54°01’11"	0.08"	137853.635m	0.0606m	1: 2275257
Z227	-46.9150m	1.0401m	-**-	-**-	1: 2275257

Appendix B
Error Ellipses and Histogram




h
H
13°
NR1
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TROY
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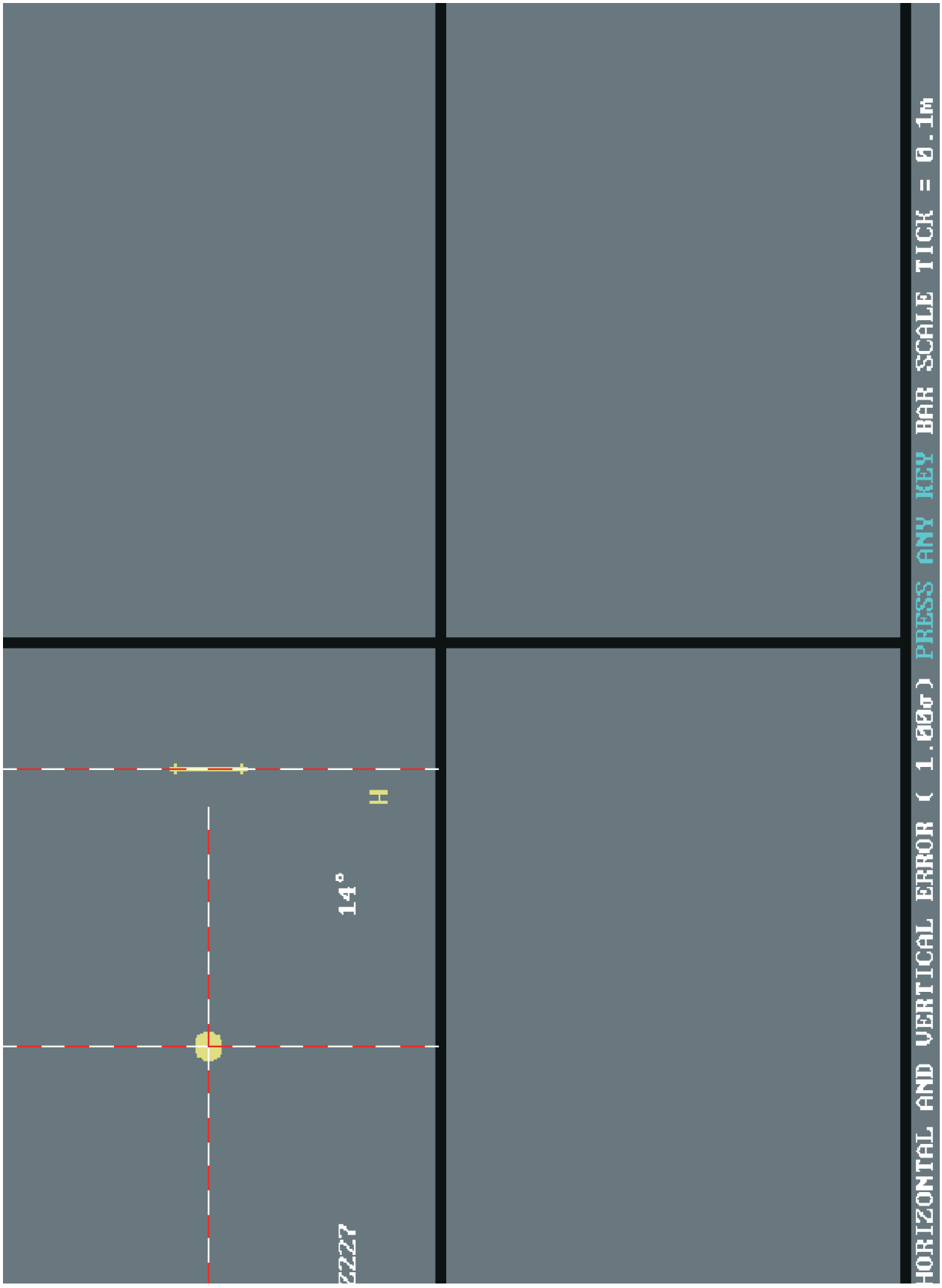
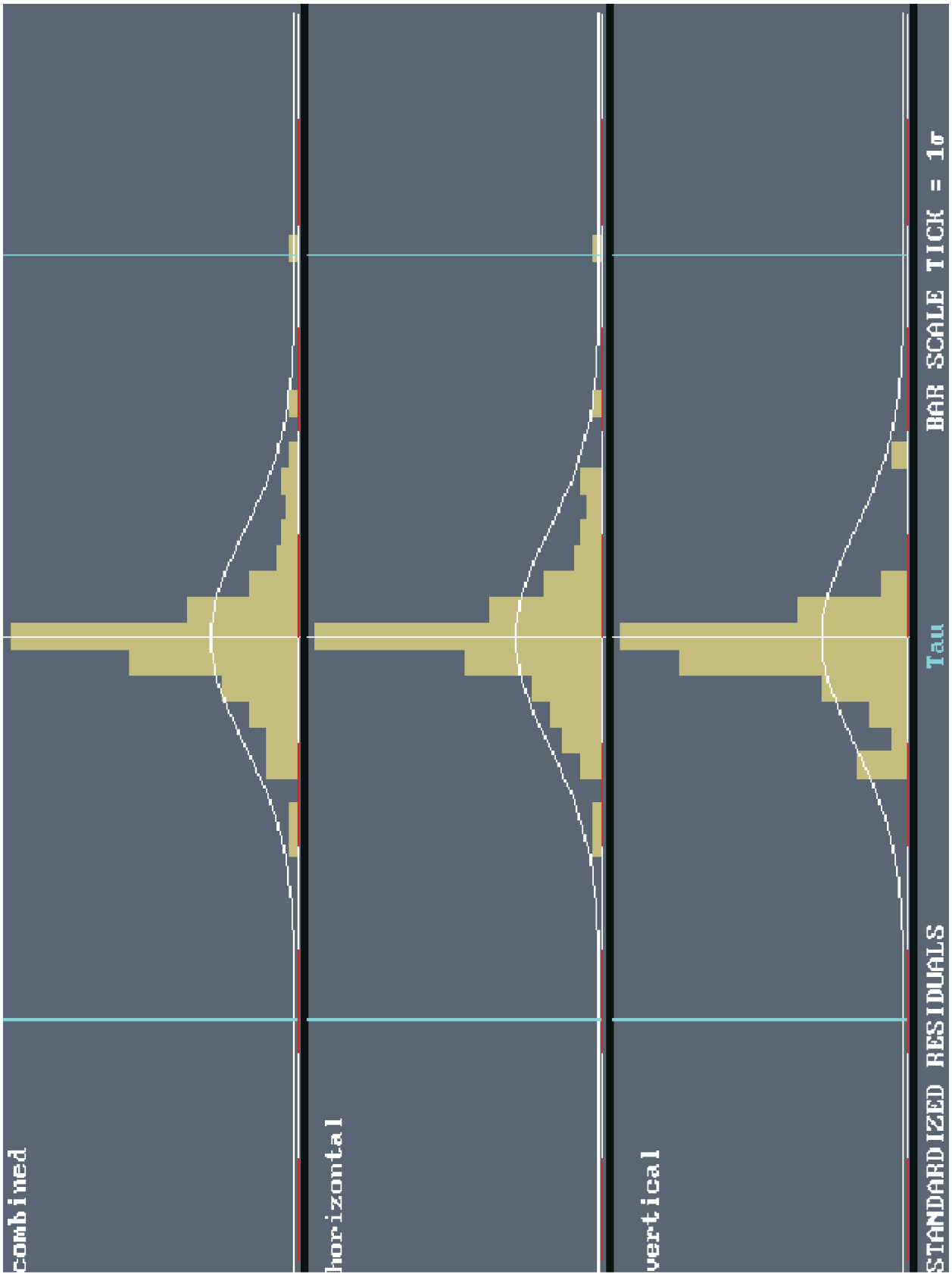
HORIZONTAL AND VERTICAL ERROR (1.00σ) PRESS ANY KEY BAR SCALE TICK = 0.1m


HORIZONTAL AND VERTICAL ERROR (1.00σ) PRESS ANY KEY BAR SCALE TICK = 0.1m
H
14°
2227


Combined
Horizontal
Vertical
STANDARDIZED RESIDUALS
Tau
BAR SCALE TICK = 1σ

Appendix C
Site Instrument Positions and Uncertainties

Name	Northing (m)	Easting (m)	Elevation (m)	Hz Acc (m)	Vt Acc (m)
B1-1	3589746.344	710182.194	92.032	0.005	0.018
B1-2	3589727.672	710180.969	93.211	0.005	0.019
B1-3	3589724.472	710191.025	93.258	0.005	0.017
B1-4	3589745.372	710188.743	92.159	0.005	0.018
B2-1	3589810.315	711480.894	131.148	0.006	0.015
B2-3	3589840.511	711497.378	134.294	0.007	0.016
B2-4	3589808.382	711507.717	132.776	0.006	0.017
B4-2	3588838.130	711817.068	124.514	0.007	0.010
B4-3	3588816.489	711809.248	123.093	0.009	0.012
B4-4	3588815.355	711798.850	122.053	0.009	0.012
B6-1	3587334.675	711463.698	124.975	0.011	0.019
B6-2	3587318.506	711477.828	124.097	0.010	0.013
B6-3	3587331.204	711498.129	123.120	0.010	0.018
B6-4	3587309.896	711448.034	125.271	0.008	0.012
B7-1	3587301.077	712751.340	127.996	0.009	0.018
B7-2	3587267.066	712740.277	124.762	0.007	0.014
B7-3	3587284.806	712724.230	125.549	0.007	0.016
B7-4	3587293.481	712728.369	127.358	0.009	0.015
B8-1	3586178.052	710260.605	149.160	0.010	0.018
B8-2	3586202.811	710247.658	149.106	0.007	0.018
B8-4	3586434.786	710490.653	144.143	0.009	0.016
B9-1	3586184.214	711554.648	125.734	0.012	0.018
B9-3	3586154.969	711573.951	125.835	0.014	0.019
B10-1	3586154.358	712766.668	151.052	0.013	0.016
B10-2	3586139.304	712758.188	153.584	0.011	0.015
B10-3	3586160.089	712731.517	147.68	0.01	0.014
B10-4	3586160.078	712731.521	147.671	0.011	0.016
L90-1	3588430.062	712628.411	149.784	0.009	0.016
L90-2	3588411.658	712656.989	147.204	0.010	0.018
L90-3	3588398.716	712652.163	146.835	0.007	0.013
L90-4	3588357.580	712853.787	146.385		
L144-1	3589311.812	709895.846	129.219	0.009	0.016
L144-4	3586415.268	710874.487	138.222	0.010	0.019
L147-1	3596526.932	707425.521	107.072	0.011	0.015
L147-2	3596539.913	707433.141	105.041	0.011	0.011
L147-3	3596521.091	707439.734	105.067	0.013	0.017
L147-4	3596543.676	707422.268	104.431	0.013	0.019

Name	Northing (m)	Easting (m)	Elevation (m)	Hz Acc (m)	Vt Acc (m)
L204-1	3590402.190	710513.454	116.022	0.011	0.015
L204-3	3590421.952	710548.992	118.089	0.014	0.018
L204-4	3590428.920	710524.552	117.046	0.012	0.016
L211-1	3586578.272	701721.553	104.948	0.009	0.014
L211-2	3586572.910	701701.552	103.244	0.010	0.017
L211-3	3586592.511	701702.900	103.098	0.009	0.016
L211-4	3586484.966	701740.989	107.711	0.009	0.016
L315-1	3589301.847	714832.630	152.509	0.010	0.019
L315-2	3589272.250	714853.908	149.788	0.011	0.019
L315-3	3589270.394	714844.952	150.213	0.009	0.016
S1-1	3590458.157	712565.015	121.878	0.009	0.013
S1-3	3590437.684	712590.918	118.174	0.010	0.016
S1-4	3590466.305	712556.047	122.784	0.012	0.018
S2-3	3588984.072	712675.654	126.144	0.013	0.015
S2-4	3588978.598	712667.832	126.405	0.011	0.013
S3-2	3589033.699	714136.276	129.994	0.007	0.014
S3-4	3589007.632	714135.738	127.074	0.007	0.015
S4-1	3587379.931	714044.238	119.843	0.008	0.016
S4-2	3587385.820	714009.724	116.165	0.008	0.014
S4-4	3587403.952	714002.031	114.669	0.006	0.013
S5-1	3587468.022	715686.339	140.696	0.006	0.011
S5-4	3587485.458	715695.245	136.949	0.008	0.017
S6-1	3586028.106	714177.522	156.609	0.010	0.014
S6-2	3586013.312	714175.307	156.655	0.010	0.017
S6-4	3586045.171	714165.838	155.651	0.011	0.015
S7-1	3585813.084	715645.053	142.023	0.013	0.019
S7-2	3585822.229	715662.405	138.091	0.012	0.016
S7-4	3585833.476	715670.466	139.344	0.008	0.012
S8-3	3585836.595	717083.306	164.906	0.010	0.017
S8-4	3585856.005	717078.133	166.088	0.010	0.016
S9-1	3584533.285	715631.838	162.769	0.009	0.014
S9-4	3584529.245	715646.148	163.669	0.011	0.019
S10-4	3584603.513	717157.092	137.914	0.005	0.017